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Particulate Organic Carbon, Nitrogen, and Chlorophyll as Measures of Phytoplankton and Detritus Standing Crops in Kaneohe Bay, Oahu, Hawaiian Islands[1]

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ABSTRACT: Data are presented to show that the Kaneohe municipal waste discharge into the southeastern corner of Kaneohe Bay gives rise to high concentrations of particulate organic matter and chlorophyll-*a*. The data cover a period of 4.5 years and show a continuing increase in particulate organic matter and chlorophyll-*a* and a significant increase in the particulate organic nitrogen: carbon ratio. It is shown that regression analyses of particulate organic carbon and nitrogen on chlorophyll-*a* can be used to estimate the phytoplankton and the detritus carbon and nitrogen concentrations in surface water samples from the eutrophic southeastern section of the bay. The differences in regression analyses results on samples from eutrophic waters as opposed to those from ologotrophic waters are discussed.

THE PHYTOPLANKTON STANDING CROP has been shown to be a particularly sensitive indicator of the degree of eutrophication in Kaneohe Bay (Caperon, Cattell, and Krasnick 1971). This plant crop together with organic detritus can have a large effect on the light environment of an aquatic marine community, particularly so in one that had been characterized previously by very clear water. Thus, there is considerable intrinsic interest in a measure of total particulate organic matter in the bay water. In addition, estimates of plant carbon and nitrogen standing crop are required if one is to evaluate the role of phytoplankton in the ecosystem where a common unit of measure of all populations is used. While there is no completely satisfactory method of measuring these variables directly, total particulate organic carbon (POC) and particulate organic nitrogen (PON) do give upper bounds for the correct values.

Chlorophyll-*a*, since it is present in the cells of all living plants, is often used as a measure of the phytoplankton standing crop. Steele and Baird (1965) have drawn attention to the good correlation between chlorophyll-*a* and POC. Holm-Hansen (1969) has shown that biomass estimates based on chlorophyll are in good agreement with those derived from direct enumeration. If the concentration of nonalgal material is constant or varies randomly and independently of algal material and if the algal carbon: chlorophyll ratio is constant, then regression analyses of carbon and chlorophyll values from the same samples can be used to calculate this ratio and to establish plant carbon and nitrogen. Riley (1965) has questioned this procedure, pointing out that one can expect that nonalgal particulate organic matter often will be correlated with algal material. Further the carbon: chlorophyll ratio in pure algal cultures varies by nearly an order of magnitude, the degree of variation depending upon the nutritional state of the algal population (Caperon and Meyer 1972) and by the amount of preconditioning light intensity (Steemann-Neilsen, Hansen, and Jorgensen, 1961). Still, in an environment with uniform light conditions and with nutrients in saturation, where one can expect a relatively constant algal carbon: chlorophyll ratio, the regression of carbon on chlorophyll should make it possible to correct POC measurements so that they are better estimates

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of plant carbon. Direct enumeration is not necessarily a very precise measure of algal standing crop (Banse et al. 1974), and the conversion of numbers to plant carbon also involves regression analyses and conversion factors that are also subject to error (Caperon and Meyer 1972). It would seem that both parameters, POC and chlorophyll-*a*, can together give better estimates of plant carbon (or nitrogen) than either one alone, especially where there are enough samples from the same environment to permit a good statistical treatment of the data.

An interpretation of the POC:PON ratios in samples of particulate organic matter from seawater is open to many of these same criticisms (Banse 1974); but if the nonalgal component is small or if the nonalgal C:N ratio is not too different from that of the plant component, then POC:PON ratios are potentially quite instructive (Caperon and Meyer 1972).

So far we have regarded increases of POC and PON as indicators of the eutrophication process, as important aspects of the physical environment, and as part of the data necessary for a determination of the standing crop of primary producers. In addition, these data are measures of the food substrate concentration for the herbivorous zooplankton, and POC and PON again represent upper bounds for estimates of the substrate concentration. If an organic particle is viewed as a food source for planktonic filter feeders, its origin—whether plant, animal, or nonliving substance—is probably not important; what is important is that the particle fall within the proper size range. *Oikopleura longicauda*, an important member of the bay plankton community, selects food particles exclusively by particle size as a necessary consequence of its feeding mechanism, and many other members of the zooplankton may be no less fastidious in their size selectivity (Frost 1974, Kerr 1971). While we could wish for better classification of food size, shape, motility, etc., better taxonomic data would not necessarily contribute to the ecological objective of using the data to estimate the food source available to the next trophic level.

METHODS

The data described here represent three sets of water samples that were collected in Kaneohe Bay and the adjacent open ocean. Figure 1 gives the station locations where samples were taken. The first set of data was collected at seven stations over a 3-month period from March through May 1970. The stations were occupied three times during each month and each station was sampled at depths of 1, 5, and 10 meters. The second set of data was collected at eight stations, with sampling at 1 and 10 m during six weekly cruises from 15 September to 20 October 1972. A third set of samples was collected at five stations in the southern portion of the bay between 14 May and 23 August 1974; sample depth for this set was 3 meters.

The two earlier sets of water samples were screened through 0.33-mm-mesh Nitex netting before being analyzed, and the last set was screened through 0.102-mm-mesh Nitex netting before being analyzed. We prescreened the first sets of samples to avoid the rather large variation that can occur when the occasional large zooplankter is collected on the filter. The prescreening in the third sample set was an attempt to eliminate as much of the zooplankton as possible without loss of plant material. The screened water of the third sample set was also used in the nutrient uptake studies reported by Harvey and Caperon (1976).

The POC and PON values for all three data sets were determined in an F & M model 185 carbon-hydrogen-nitrogen analyzer. Selas Flotronics silver filters with a pore size of 1.2 μm were used for the 1970 and 1972 data sets, and Whatman glass fiber filters, grade C (GFC filters), for the third data set. In all cases, the sample volume was such that a sample could be filtered with gentle suction in less than 20 minutes. This procedure provided sufficient material to give good precision in the C and N determinations. The silver filters were treated as described by Gordon (1969) and the glass fiber filters were handled as described by Sharp (1974).

Chlorophyll-*a* values were determined for the 1-meter-depth samples in the 1970 data set and for all samples in the 1972 and 1974 data. For all three data sets, the material collected on

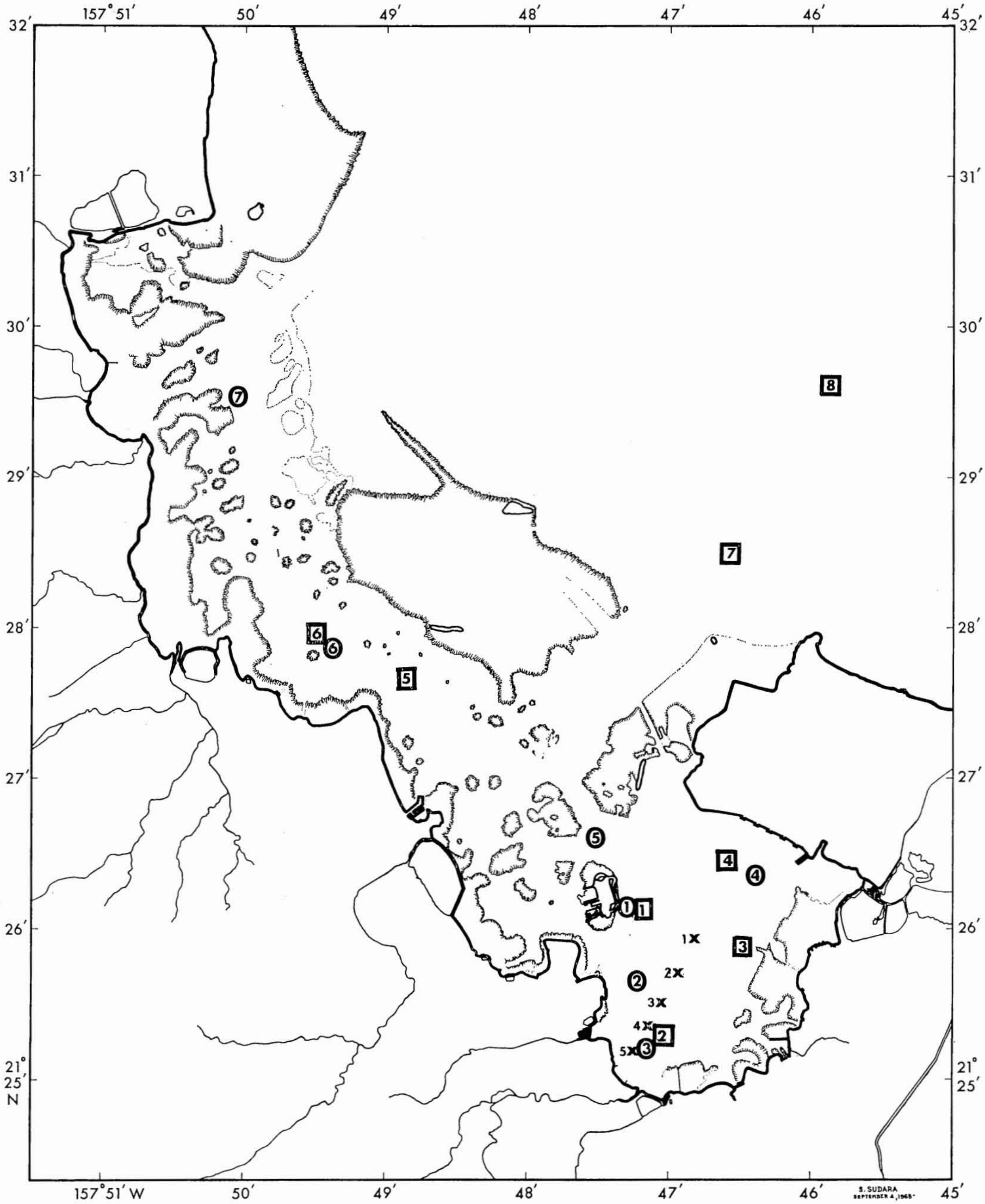

FIGURE 1. A map of Kaneohe Bay showing the locations of sampling stations. The circled numbers represent spring 1970 stations, the numbers in squares represent fall 1972 stations, and the numbered X's represent summer 1974 stations.

Whatman GFC filters was analyzed by the trichromatic method as described by Strickland and Parsons (1968).

When we use the word "significant" in a statistical context, we mean the 5-percent significance level.

TABLE 1

STATION MEANS OF PARTICULATE CARBON, NITROGEN, AND CHLOROPHYLL-*a*, KANEOHE BAY, OAHU, HAWAII

STATION NUMBER	DEPTH (m)	NUMBER OF SAMPLES TESTED	CARBON (μg/liter)	NITROGEN (μg/liter)	CHLOROPHYLL-*a* (μg/liter)
Spring 1970					
1	1	9	263 (72)	38.5 (10.5)	1.44 (0.46)
1	5	7	219 (114)	31.8 (12.9)	
1	10	7	256 (69)	38.1 (11.4)	
2	1	9	292 (110)	50.9 (20.7)	2.67 (1.68)
2	5	8	320 (107)	47.0 (14.5)	
3	1	9	463 (156)	78.2 (23.7)	3.41 (1.98)
3	5	8	264 (82)	45.4 (12.4)	
4	1	7	166 (55)	31.2 (9.4)	1.20 (0.51)
4	5	8	162 (60)	30.8 (12.2)	
4	10	7	169 (63)	29.8 (11.1)	
5	1	8	136 (24)	24.1 (2.8)	1.03 (0.42)
5	5	7	136 (31)	21.6 (5.5)	
5	10	7	160 (32)	25.5 (5.0)	
6	1	8	131 (51)	19.2 (6.6)	0.49 (0.23)
6	5	7	106 (41)	18.5 (6.8)	
6	10	7	129 (34)	20.1 (4.3)	
7	1	8	68 (19)	13.2 (3.8)	0.48 (0.08)
7	5	6	66 (18)	12.9 (4.8)	
7	10	6	81 (26)	10.4 (5.5)	
Fall 1972					
1	1	6	322 (121)	39.1 (14.7)	2.23 (0.91)
1	10	6	341 (80)	54.3 (13.7)	4.02 (1.52)
2	1	6	366 (110)	55.8 (13.7)	2.89 (0.76)
2	10	6	351 (67)	51.8 (10.6)	3.79 (0.86)
3	1	6	317 (157)	45.5 (17.0)	2.21 (1.40)
3	10	6	347 (72)	51.2 (20.1)	4.05 (1.81)
4	1	6	294 (114)	37.4 (8.6)	2.02 (0.75)
4	10	6	334 (110)	42.0 (17.0)	3.85 (2.14)
5	1	6	224 (82)	26.8 (11.1)	1.10 (0.18)
5	10	6	309 (110)	31.2 (8.1)	2.21 (1.25)
6	1	6	171 (56)	21.7 (6.0)	1.28 (1.10)
6	10	6	237 (49)	27.7 (7.6)	1.23 (0.45)
7	1	6	66 (44)	7.8 (4.3)	0.18 (0.16)
8	1	5	47 (13)	6.4 (2.8)	0.17 (0.05)
Summer 1974					
1	3	3	363 (54)	57.5 (14.9)	1.99 (1.18)
2	3	1	461 (—)	72.5 (—)	5.84 (—)
3	3	3	579 (93)	103.9 (23.7)	5.31 (2.58)
4	3	7	546 (136)	94.1 (27.2)	4.73 (2.31)
5	3	4	436 (92)	73.1 (26.0)	3.42 (1.57)

NOTE: Numbers in parentheses represent standard deviation.

RESULTS

Table 1 gives the station means and standard deviations of POC, PON, and chlorophyll-*a* over each of the three sampling periods. No replicate samples were taken, but a 24-hour time series of 12 samples taken at 2-hour intervals at four depths at a single location on 2 April 1970 showed no trend or discernible pattern in concentration of POC or PON. Therefore, we used these time series samples to estimate sampling variability. Table 2 gives the means and standard deviations of POC and PON for each depth for this time series. The variability due to the

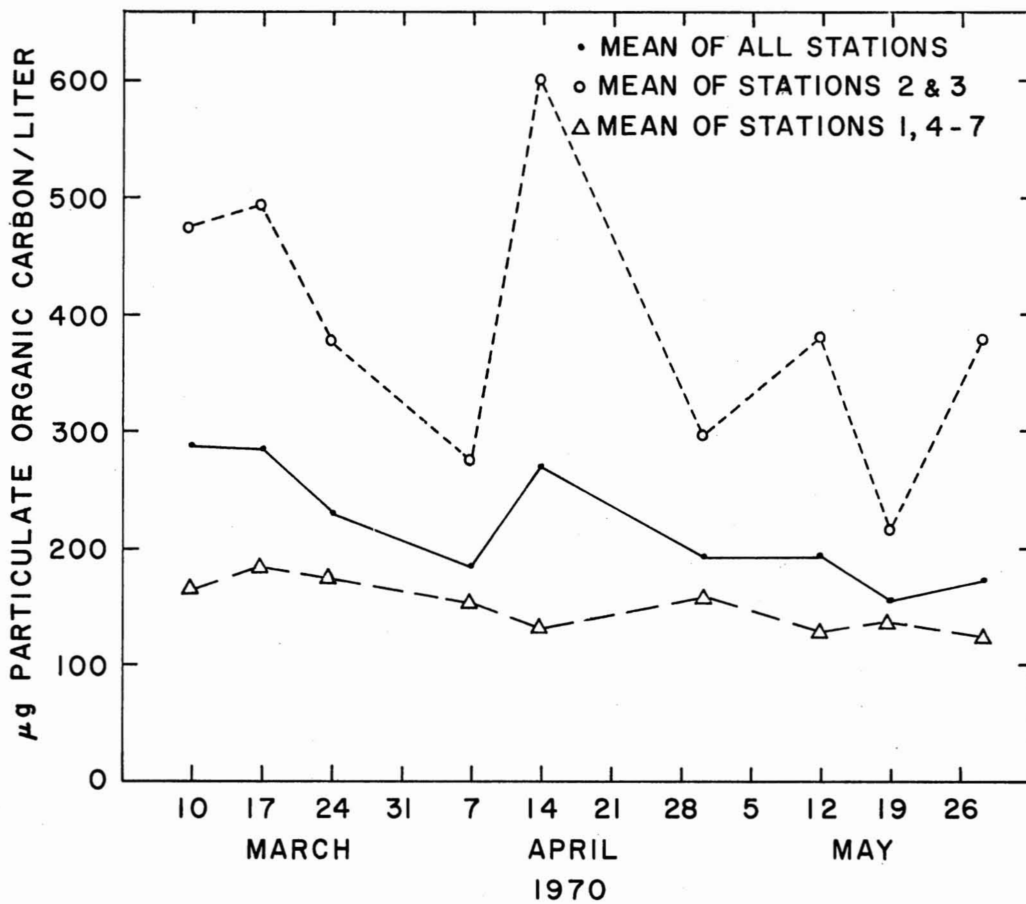

FIGURE 2. Particulate organic carbon concentration as a function of time during spring 1970. Stations 2 and 3 (dashed line with open circles) are near the Kaneohe municipal waste discharge site.

TABLE 2

MEANS AND STANDARD DEVIATIONS OF PARTICULATE ORGANIC CARBON AND PARTICULATE ORGANIC NITROGEN AT DIFFERENT DEPTHS IN A 24-HOUR TIME SERIES, KANEOHE BAY, OAHU, HAWAII

DEPTH (m)	CARBON (μg/liter)	NITROGEN (μg/liter)
0	172 (38)	30 (10)
3	146 (31)	25 (8)
7	139 (13)	22 (3)
11	187 (45)	24 (5)

NOTE: Twelve samples were tested at 2-hour intervals at a single location (station 1) during April 1970. Standard deviations are shown in parentheses.

analytical procedure was negligible compared to sampling variability. Since the sampling variability for this time series was about one-half that for the nearby station 1 for the 3-month sampling period represented by the 1970 data, we looked for possible temporal variability in the data. Figure 2 gives the mean POC for the whole bay, for stations 2 and 3, and for the remaining 4 stations as a function of time. Most of the temporal variability in the samples can be accounted by for stations 2 and 3. The data also show a slight but discernible decreasing trend in concentration of POC during the 3 months covered by the 1970 sample series. The correlation coefficient between POC and the standard deviation of POC over the 3 months sampled is

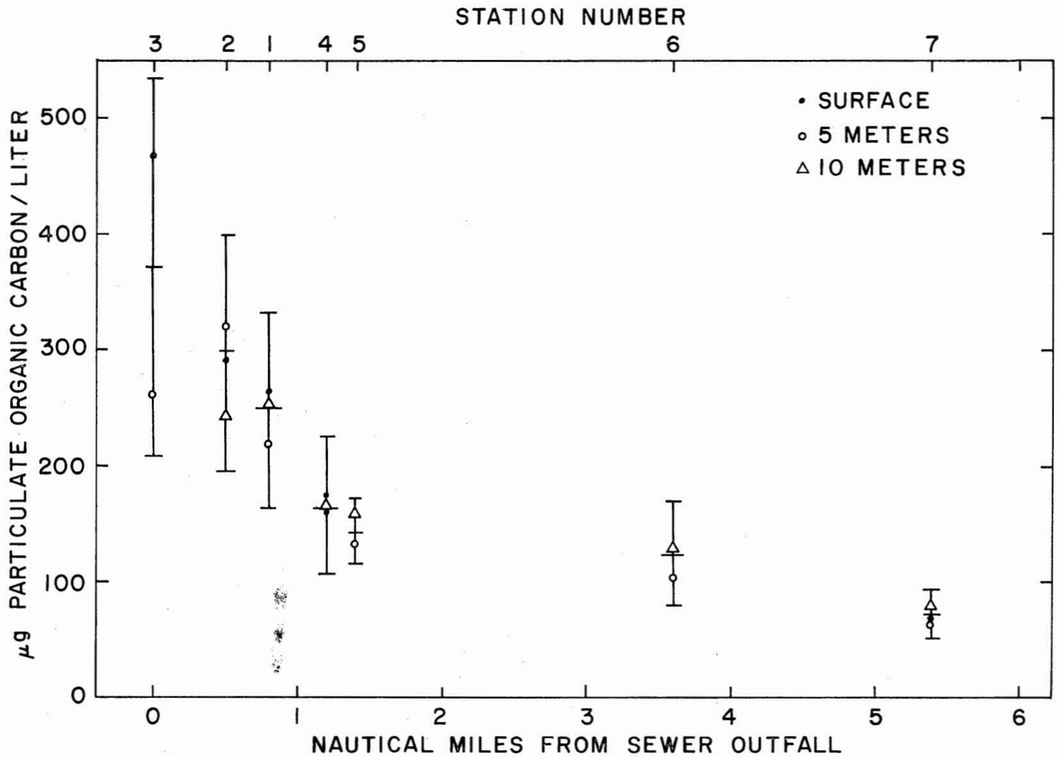

FIGURE 3. Particulate organic carbon concentration as a function of distance from the Kaneohe municipal waste discharge site for the spring 1970 data. The central horizontal bar at each station represents the mean value for all samples; the vertical bar represents the 95-percent confidence limits of this mean; and the filled circle, open circle, and open triangle represent the surface, 5-meter, and 10-meter means, respectively.

0.927. Thus, the increase in mean POC is accompanied by an increase in variability.

The spatial variability of POC can be accounted for largely by the distance of the sample station from the Kaneohe municipal waste discharge location. Figure 3 shows a rapid decrease in both the concentration and variability of POC with distance away from the outfall site. This is to be expected, since this location is the major source of nutrient enrichment in the bay (Caperon 1974). Only the value at station 4 is surprising since this station is quite near the waste discharge site of the Kaneohe Marine Corps Air Station. Even though this source discharges only about one-third the waste products of the municipal source, still the absence of any apparent effects because of its activities is puzzling. The data presented in Table 1 and Figure 3 show that there is no clear pattern of difference in concentration with sample depth.

All of the statements made above relative to POC for the 1970 series hold equally well for PON. Figure 4 shows how well correlated these two variables are in the bay, where they exhibit an order of magnitude range of variation. The correlation coefficient is 0.945; and the slope, which equals the C:N ratio (weight:weight), is 5.89. The zero intercept on the carbon axis is 6.91 μg POC/liter, which is not significantly different from zero. The results of the regression analyses for carbon on nitrogen for the surface values of all three data sets are given in Table 3.

The regression analyses results for carbon on chlorophyll-*a* and nitrogen on chlorophyll-*a* for the surface samples for the stations in the southeastern section of the bay are also given in Table 3. All six regressions show significant correlations between the variables. For the 1970 and 1972 data sets the inclusion of data from stations outside the southeastern section results in poor correlation between the variables.

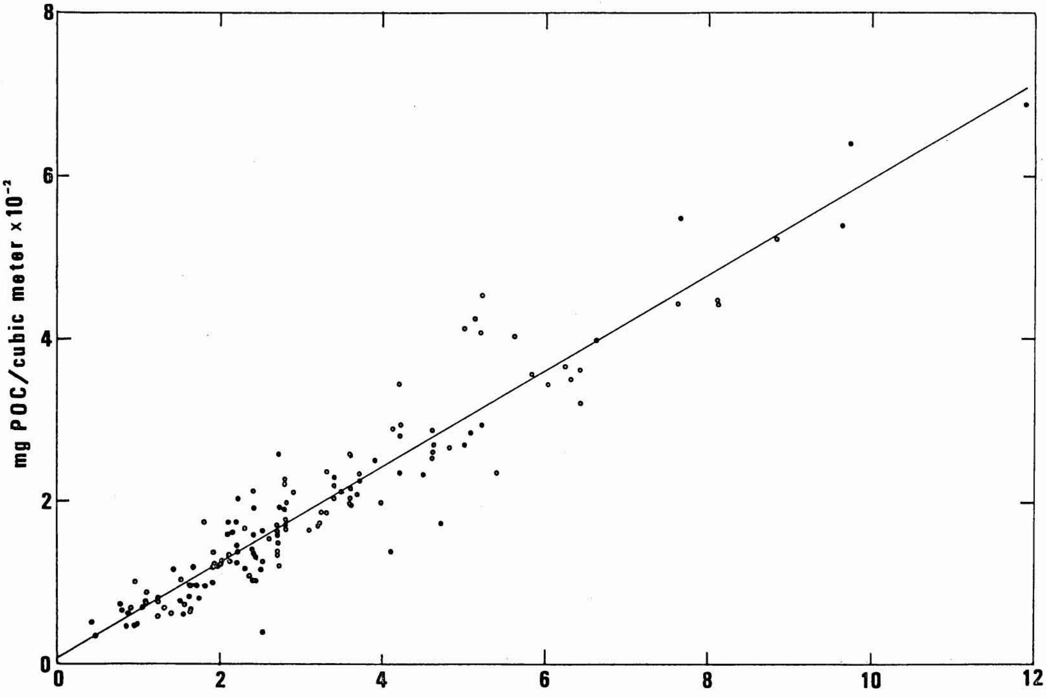

FIGURE 4. The linear regression of particulate organic carbon (POC) versus particulate organic nitrogen (PON) for the 1970 data.

TABLE 3

REGRESSION ANALYSES RESULTS FOR CARBON ON NITROGEN AND FOR CARBON AND NITROGEN ON CHLOROPHYLL-*a* FOR THE PARTICULATE ORGANIC FRACTION OF SURFACE WATER SAMPLES FROM KANEOHE BAY, OAHU, HAWAIIAN ISLANDS

REGRESSION EQUATIONS*	CORRELATION COEFFICIENTS
Spring 1970	
C = 5.89 N + 6.91	0.945
†C = 114 Cl + 95.6	0.664
†N = 22.03 Cl + 14.3	0.738
Fall 1972	
C = 5.06 N + 96.2	0.761
†C = 97.8 Cl + 96.0	0.790
†N = 12.72 Cl + 14.7	0.838
Summer 1974	
C = 4.63 N + 105.5	0.976
†C = 54.1 Cl + 278.3	0.938
†N = 11.5 Cl + 38.1	0.948

NOTE: Results are presented for three sample series that were taken in spring 1970, fall 1972, and summer 1974.

* C, carbon; N, nitrogen; and Cl, chlorophyll-*a*.

† Data are for the southeastern section of the bay only.

Carbon, or nitrogen, on chlorophyll-*a* regression analyses for individual stations generally shows poor correlation for stations outside the southeastern section and generally good correlation for stations inside.

POC and PON are not as highly correlated with chlorophyll-*a* as they are with each other; however, the correlations are significant, and the same temporal and spatial patterns shown in Figures 2 and 3 for POC are also exhibited by the chlorophyll values.

The fall 1972 data (Table 1) show a generally higher and a more broadly and evenly distributed region of high concentration of particulate carbon, nitrogen, and chlorophyll-*a* in the southeastern part of the bay. Compared with the spring 1970 data, those for station 6, in the more northerly part of the bay, also show significantly higher concentrations. Analyses of variance (stations versus cruise dates) show that the three groups comprising stations 1 to 4, 5 and 6, and 7 and 8 had statistically significant differences in the mean concentrations for all three variables at both the surface and 10-meter depths. Means of all three variables among stations 1, 2, 3, and 4 were not significantly different for either depth. Depth differences for these four stations were not significant for POC or PON, but were significant for chlorophyll-*a*. Therefore, we have used only the surface values for stations 1 to 4 in the chlorophyll regression analyses presented in Table 3. The effect of shade adaptation is clearly shown by the decreased carbon: chlorophyll ratio for the surface and 10-meter means for stations 1, 2, 3, and 4. The four ratios for the surface samples are 144, 127, 143, and 146, while the ratios for the 1-meter samples are 85, 93, 86, and 87, respectively. This difference is due to increased chlorophyll in the presence of essentially the same POC concentration. Stations 5 and 6 are in clearer water; therefore, this pronounced difference in carbon: chlorophyll ratio is not evident.

The summer 1974 data are all from the most eutrophic part of the southeastern section of the bay. They show significantly increased concentrations of POC, PON, and chlorophyll-*a* relative to comparable locations in the 1970 and 1972 data sets. The regression analyses presented in Table 3 show that all three variables are very closely correlated.

DISCUSSION

There is a very clear trend of increasing concentrations of POC, PON, and chlorophyll-*a* during the 4 years represented by these three data sets. For example, the mean values for the stations located in the southern sector of the bay are 257.4, 334.0, and 477.0 μg/liter POC, 42.2, 47.1, and 80.2 μg/liter PON, and 2.2, 3.1, and 4.3 μg/liter chlorophyll-*a* for the spring 1970, fall 1972, and summer 1974 sampling periods, respectively. Since the data sets represent three different seasons, one must consider the possibility that this trend is due to seasonal variation rather than to a long-term change. Krasnick (1973) found a relatively stable mean of about 2.4 μg/liter chlorophyll-*a* from January through August, followed by an increase to a September through December peak of about 3.5 μg/liter chlorophyll-*a*. This peak can be explained at least partly by higher runoff into the bay during October to December, but neither fall 1972, nor the summer 1974 was a period of high rainfall. It is considered more likely, therefore, that this trend is real and that it reflects the continuing process of eutrophication from increased urbanization in the watershed and increasing amounts of waste being discharged into the bay. The 1974 data are biased by the location of the sampling stations in the more eutrophic part of the southern basin, but still they are much higher than data gathered earlier from comparably located areas. The finer prescreening for the 1974 samples could only tend to make the values lower in comparison with those from earlier samples. It is important to note that the temporal increase in POC, PON, and chlorophyll-*a* was not accompanied by an increase in the observed concentration of nitrate, phosphate, and ammonium (Caperon, Cattell, and Krasnick 1971; Krasnick 1973; and unpublished nutrient data).

The carbon: nitrogen ratio as developed from the slopes of the regression analyses in Table 3 shows a statistically significant shift toward increased organic nitrogen relative to carbon. The summer 1974 slope of 4.63 is significantly lower than is the 5.89 slope for the spring 1970 data. Because of the larger variability of the 1972 data, the 5.06 slope does not differ from either of these two values significantly, but the intermediate value does support the trend toward lower C:N ratios. This decrease in the C:N ratio could have occurred if there had been an increasing amount of animal matter relative to plant and detritus. Hirota and Szyper (1976) gave a mean C:N value of 4.0 for the macrozooplankton, and Bartholomew (1973) gave a value of 4.1 for the microcopepods. Some microzooplankton were included in the 1970 and 1972 samples (prescreened with 333-μ mesh net), but the 1974 samples which gave the lowest C:N ratio were prescreened through a 102-μ mesh net, which effectively eliminated most of the zooplankton. This lower C:N ratio could also have been due in part to the changing nutritional state of the phytoplankton (Caperon and Meyer 1972). With increasing amounts of fixed nitrogen coming into the bay, both the standing crop and the nitrogen per unit population of the phytoplankton would be expected to increase, and the shift in the C:N ratio also supports the contention that there is increasing eutrophication in the bay. The mean C:N ratios for stations 7 and

8 from outside the bay in the 1972 data were 7.8 and 7.3. A 1-year study at an open-ocean station near Oahu produced a mean value for surface waters (0–100 meters) of 6.9 (Gordon 1971). How much of this variation is due to changes in the algal component relative to comparably sized particles of detritus is still an open question. Differences in the treatment of samples for POC and PON between the 1970 and 1972 data sets and the 1974 data set are not considered significant (Gordon and Sutcliffe 1974, Sharp 1974).

The relationships between carbon and chlorophyll-*a* and between nitrogen and chlorophyll-*a* are difficult to interpret. The regressions of carbon and nitrogen on chlorophyll-*a*, presented in Table 3, are significant for all cases. Only stations from the southeastern section of the bay have been included in these regressions. The inclusion in the 1970 and 1972 data sets of stations from the other parts of the bay and/or the open ocean resulted in low, nonsignificant correlation coefficients. These areas are much lower in chlorophyll concentration than is the southeastern section. Regression analyses for individual stations gave generally high correlation coefficients for the southeastern section and uniformly low coefficients for the other stations. These results are similar to those of Steele and Baird (1965) whose North Sea data show good correlation between carbon and chlorophyll from April to October (high algal crops) and poor correlation in the winter months (low algal crops). We compared these North Sea data showing seasonal change from oligotrophy to eutrophy in the North Sea with our spatial change from oligotrophy in the northern part of the bay and the offshore waters to eutrophy in the southeastern section. It does not seem that variation in the algal carbon: chlorophyll ratio is a sufficient explanation for the lack of correlation in data from our low chlorophyll station samples, since there is no light adaptation and there appear to be sufficient nutrients to support a high phytoplankton growth rate (Krasnick 1973). The presence of a relatively large and at least partly uncorrelated nonalgal component comprising detritus and animals in the POC is indicated.

The good correlations between POC or PON and chlorophyll-*a* for eutrophic systems and the poor correlations for oligotrophic systems can be explained by reference to the planktonic ecosystem model developed by Caperon (1974) for Kaneohe Bay. The model describes the way that organic nitrogen is partitioned between detritus, phytoplankton, and zooplankton for various nutrient (nitrogen) input rates. The relevant feature of this model to which we wish to call attention is that the phytoplankton fraction for oligotrophic systems (those associated with low input rates) is small compared to the detritus fraction. The change in phytoplankton standing crop relative to change in nutrient input rate is small in this range of input rate, while the change in detritus standing crop with input rate is maximal. Thus, one would expect that both the total particulate nitrogen (PN) and the variability of PN in oligotrophic systems would be dominated more by detritus than by phytoplankton. This would result in a poor correlation between PN and chlorophyll. Just the reverse is true for eutrophic systems (those associated with high input rates). The PN becomes more dominated by the phytoplankton standing crop and the response of the phytoplankton to change in the input rate is maximal. The response of the detritus standing crop to change in the input rate is minimal in this range. This situation would be expected to produce a high correlation between PN and chlorophyll, while at the same time the detritus component of the PN becomes relatively invariant. Under this circumstance the regression slope gives a good estimate of the phytoplankton nitrogen: chlorophyll ratio and the zero intercept is a good estimate of the detritus component of the PN.

The phytoplankton population in the bay is heavily dominated by diatoms (Murphy 1972). The carbon: chlorophyll and nitrogen: chlorophyll data from Caperon and Meyer (1972) for a diatom, *Thalassiosira pseudonana* (formerly *Cyclotella nana*), in continuous culture are presented in Table 4. It can be seen that the carbon: chlorophyll and nitrogen: chlorophyll ratios at light saturation vary systematically as a function of steady-state growth rate. As the growth rate approaches the maximum specific growth rate, i.e., when nutrient limitation becomes much less intense, the ratios approach constant values. The mean carbon: chlorophyll-*a* and nitrogen:

TABLE 4

STEADY STATE CONTINUOUS CULTURE CARBON TO CHLOROPHYLL-*a* AND NITROGEN TO CHLOROPHYLL-*a* RATIOS FOR *Thalassiosira pseudonana* (FORMERLY *Cyclotella nana*) AND VARIOUS GROWTH RATES UNDER NITRATE-LIMITING CONDITIONS

GROWTH RATE (hr^{-1})	CARBON: CHLOROPHYLL $\mu g:\mu g$	NITROGEN: CHLOROPHYLL $\mu g:\mu g$
0.0087	500	29.2
0.0176	333	31.1
0.0363	260	24.7
0.0402	138	17.8
0.0445	113	14.3
0.0478	68	11.2
0.0632	71	9.9
0.0708	55	10.2
0.0768	76	11.6

NOTE: See Caperon and Meyer (1972) for a full description of experiment.

chlorophyll-*a* ratios over the four highest steady state growth rates are 67 and 10.7 weight: weight ratios, respectively. These are quite close to the regression slopes (ratios) of 54 and 11.5 for the 1974 data. Eppley and Renger (1974) gave lower ratios for this species growing under light-dark cycle conditions, but diurnal variation in this ratio would have to be examined before these data could be interpreted in the present context.

For three samples from the southeastern section of the bay, the POC, PON, chlorophyll-*a*, microzooplankton C and N (passing through 0.333-mm mesh and retained by 0.035-mm mesh), and nanozooplankton (< .035-mm mesh) C and N have been determined (Schell, Hirota, and Caperon, unpublished). The POC, PON, and chlorophyll-*a* were determined as described for the 1974 data in this paper. We determined the carbon and nitrogen content of the microzooplankton by microscopic identification and converted enumeration counts to carbon and nitrogen using factors developed for each species (Hirota and Szyper 1976). Carbon and nitrogen of protozoan origin were determined by microscopic enumeration and size measurement of the animals, followed by a volume calculation and use of the appropriate carbon and nitrogen per unit volume conversion factors. We converted chlorophyll-*a* to C and N using the regression slopes for the 1974 data in Table 3. The detritus C and N were then determined as the difference between POC (or PON) and all living components, i.e., plant + microzooplankton + protozoan carbon (or nitrogen). This gave detritus estimates for nitrogen of 37, 28, and 17 μg/liter, which compare well with the regression intercept value of 38 for the 1974 data. The detrital carbon estimates for the same three samples are 305, 257, and 277, which also compare well with the regression intercept of 278. Thus, having used regression analyses, we feel confident that the size fractionation techniques used in the treatment of samples for the 1974 data set give accurate estimates of the algal standing crop in terms of chlorophyll-*a*, or carbon or nitrogen and that the regression intercept at zero chlorophyll is a good measure of the nonliving POC or PON.

We conclude that in waters low in chlorophyll-*a* the likely variability of plant carbon: chlorophyll and nitrogen: chlorophyll ratios plus the relatively larger fraction of uncorrelated nonplant POC and PON render regression analyses on POC, PON, and chlorophyll-*a* data of limited use in determining plant and detritus carbon and nitrogen. It would be interesting to attempt careful prescreening studies based on microscopic size studies of the resident phytoplankton to see how close one could come to good estimates by processing numerous large samples from low-chlorophyll waters. In waters with high chlorophyll, the method described in this paper appears to give good estimates of plant and detritus carbon or nitrogen.

LITERATURE CITED

BANSE, K. 1974. On the interpretation of data for the carbon to nitrogen ratio of phytoplankton. Limnol. Oceanogr. 19: 695–699.

BANSE, K., M. BERNHARD, R. W. EPPLEY, G. R. HASLE, R. MARUMO, G. A. ROBINSON, G. I. SEMINA, and T. J. SMAYDA. 1974. A review of methods used for quantitative phytoplankton studies. UNESCO Tech. Pap. Mar. Sci. 18.

BARTHOLOMEW, E. F. 1973. The production of microcopepods in Kaneohe Bay, Oahu, Hawaii. M.S. Thesis. University of Hawaii, Honolulu. 91 pp.

CAPERON, J. 1974. A trophic level ecosystem model analysis of the plankton community in a shallow water subtropical estuarine embayment. Pages 691–709 *in* L. E. Cronin, ed. Estuarine research. Vol. 1. Chemistry, biology and the estuarine system. Academic Press, New York.

CAPERON, J., S. A. CATTELL, and G. KRASNICK. 1971. Phytoplankton kinetics in a subtropical estuary: eutrophication. Limnol. Oceanogr. 16(4): 599–607.

CAPERON, J., and J. MEYER. 1972. Nitrogen-limited growth of marine phytoplankton. I. Changes in phytoplankton characteristics with steady-state growth rate. Sea-Deep Res. 19: 601–618.

EPPLEY, R. W., and E. H. RENGER. 1974. Nitrogen assimilation of an oceanic diatom in nitrogen-limited continuous culture. J. Phycol. 10: 15–23.

FROST, B. W. 1974. Feeding processes at lower trophic levels in pelagic communities. Pages 59–77 *in* C. B. Miller, ed. The biology of the oceanic Pacific. Oregon State University Press, Corvallis.

GORDON, D. C., JR. 1969. Examination of methods of particulate organic carbon analysis. Deep-Sea Res. 16: 661–669.

———. 1971. Distribution of particulate organic carbon and nitrogen at an oceanic station in the central Pacific. Deep-Sea Res. 18: 1127–1134.

GORDON, D. C., and W. H. SUTCLIFFE, JR. 1974. Filtration of seawater using silver filters for particulate nitrogen and carbon analysis. Limnol. Oceanogr. 19: 989–993.

HARVEY, W. A., and J. CAPERON. 1976. The rate of utilization of urea, ammonium, and nitrate by natural populations of marine phytoplankton in a eutrophic environment. Pac. Sci. 30(4): 329–340.

HIROTA, J., and J. P. SZYPER. 1976. Standing stocks of zooplankton size-classes and trophic levels in Kaneohe Bay, Oahu, Hawaiian Islands. Pac. Sci. 30(4): 341–361.

HOLM-HANSEN, O. 1969. Determination of microbial biomass in ocean profiles. Limnol. Oceanogr. 14: 740–747.

KERR, S. R. 1971. Prediction of fish growth efficiency in nature. J. Fish. Res. Board Can. 28: 809–814.

KRASNICK, G. 1973. Temporal and spatial variations in phytoplankton productivity and related factors in the surface waters of Kaneohe Bay, Oahu, Hawaii. M.S. Thesis. University of Hawaii, Honolulu. 91 pp.

MURPHY, C. 1972. An annual cycle of phytoplankton populations in Kaneohe Bay, Oahu. M.S. Thesis. University of Hawaii, Honolulu. 109 pp.

RILEY, G. A. 1965. A mathematical model of regional variations in plankton. Limnol. Oceanogr. 10 (suppl.): R202–R215.

SHARP, J. H. 1974. Improved analysis for "particulate" organic carbon and nitrogen from seawater. Limnol. Oceanogr. 19: 984–989.

STEELE, J. H., and I. E. BAIRD. 1965. The chlorophyll-*a* content of particulate organic matter in the northern North Sea. Limnol. Oceanogr. 10: 261–267.

STEEMANN-NIELSEN, E., V. K. HANSEN, and E. G. JORGENSEN. 1961. The adaptation to different light intensities in *Chlorella vulgaris* and the time dependence on transfer to a new light intensity. Physiol. Plant. 12: 353–370.

STRICKLAND, J. D. H., and T. R. PARSONS. 1968. A practical handbook of sea water analysis. Bull. Fish. Res. Board Can. 167. 311 pp.